California Energy Commission

CONSULTANT REPORT

California Off-Road Transportation Electrification Demand Forecast

Prepared for: **California Energy Commission**
Prepared by: **UC Davis Institute of Transportation and Aspen Environmental Group**

California Energy Commission

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September 2016 | CEC-200-2016-014

California Energy Commission

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Contract Number: 800-13-001

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ACKNOWLEDGEMENTS

This report and the off-road vehicles forecast was prepared by Marshall R. Miller as a subcontractor to Aspen Environmental Group, under Contract No. 800-13-001. Ashley Spalding of the Aspen Environmental Group provided technical support in building the model that houses the calculations and in finalizing the report. Catherine Elder, Aspen Environmental Group, provided general program support.

ABSTRACT

This study generates an electrification forecast in California for off-road vehicles from 2015 through 2026. The forecasts include both estimates of the electricity usage for off-road vehicles and the avoided petroleum fuel from switching to electricity. The off-road vehicles and equipment sectors covered by the study include airport ground support equipment, forklifts, plug-in hybrid work trucks, transport refrigeration units, port cargo handling equipment, shore power, and truck stop electrification.

For each off-road sector, the present and projected population of all vehicles or equipment types is determined. The percentage of vehicles or pieces of equipment that will be electrified is estimated and the population calculated. The associated electricity usage is then calculated using estimates of the vehicle or equipment fuel economy and activity (vehicle miles traveled or hours of operation). The avoided petroleum usage is calculated by determining the number of electric vehicles or pieces of equipment that have been substituted for petroleum-fueled vehicles using the fuel economy and activity for those petroleum-fueled vehicles.

The off-road demand forecast includes three cases: low, mid, and high. The projected vehicle/equipment populations for the various applications in this study are based on the mid, high and low forecast of 2015-2026 California gross state product from the 2015 Moody's Analytics and the 2015 IHS Global Insight scenarios for California as used in the *2015 Integrated Energy Policy Report*. The other difference between the off-road demand forecast cases is the percentage electrification for off-road vehicles. The low, mid, and high cases represent minimal, expected, and aggressive increases in electrification, respectively.

Keywords: California Energy Commission, electricity demand forecast, off-road vehicles, forklifts, airport ground support equipment, utility work trucks, transport refrigeration units, port cargo handling equipment, shore power, truck stop, transportation, electrification

Please use the following citation for this report:

Miller, Marshall R. UC Davis Institute of Transportation and Aspen Environmental Group, 2016. ***California Off-Road Transportation Electrification Demand Forecast.*** California Energy Commission. Publication Number: CEC-200-2016-012.

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EXECUTIVE SUMMARY

This analysis produces forecasts of California electrification and electricity demand between 2015 and 2026, for the off-road vehicle and equipment sectors listed below:

- Airport ground support equipment
- Forklifts
- Plug-in hybrid work trucks
- Transport refrigeration units
- Port cargo handling equipment
- Shore power
- Truck stop electrification

These forecasts include both estimates of the electricity usage for off-road vehicles and the avoided petroleum fuel consumption resulting from switching to electricity. There are three demand forecast cases – low, mid, and high – representing minimal, expected, and aggressive increases in electrification, respectively.

Forecasted electricity usage and avoided fuel consumption values for each demand case are based on estimates of total fleet population, proportion of fleet electrification, and the average annual electricity usage per vehicle. These input estimates are derived from state and national agency reports, research papers, and discussions with experts. In some instances, agency reports and research papers allow the authors to estimate these inputs with some confidence for each demand case. In other instances, rough estimates were developed based on discussions with experts and the consideration of projections from reports.

In each sector of off-road equipment considered in this study, there is increased electrification or plans to electrify fleets. This increase in electrification is driven by equipment costs and regulation. For example, the cost to own and operate electric equipment may be lower than the cost of petroleum-fueled equipment, which drives fuel switching. In other circumstances, existing or expected regulation drives owners to electrify their fleets.

This study describes specific opportunities for fuel switching to electricity for each off-road sector. Potential benefits of electrification include quiet operation, the potential to meet current or future environmental regulations, and lower total cost of ownership for vehicles or equipment. Potential barriers to switching may include increased upfront cost and the lack of commercial electrified vehicles or infrastructure.

Table ES-1 shows low, mid, and high off-road electricity demand forecasts for 2015, 2020, and 2026.

Table ES-1: Statewide Electricity Usage for Off-Road Vehicles and Equipment

	Electricity Usage (GWh)		
	2015	2020	2026
Mid	1,365	1,882	2,445
High	1,365	2,195	3,267
Low	1,365	1,657	1,896

Source: Aspen team analysis

The spread in the forecasts results from two factors – the projected increase in the gross state product and the estimated percentage electrification for vehicles and equipment. The estimated percentage of electrification dominates the spread in low, mid, and high demand forecasts and varies by off-road sector; the difference between the low and high forecasts ranges from 10 percent to 50 percent.

Forklifts dominate the electricity usage, with shore power being the next most significant sector. The increase in electricity usage from 2015 to 2026 varies from roughly 500 to 1,900 gigawatt-hours for the low and high forecasts, respectively. This increase represents an extremely small projected change in the overall state electricity usage.

Table ES-2: Avoided Fuel Usage for Off-Road Vehicles and Equipment, Diesel Gallon Equivalent

	Avoided Petroleum (Million Gallons DGE)		
	2015	2020	2026
Mid	0	54	118
High	0	105	252
Low	0	16	24

Source: Aspen team analysis

Electrification in these off-road sectors could potentially reduce petroleum consumption between 24 million to 252 million gallons by 2026, as shown in **Table ES-2**.

CHAPTER 1: Introduction

This study produces forecasts of electricity use by off-road vehicles and equipment in California over the 2015 to 2026 period. These forecasts were integrated into the electricity demand forecast adopted as part of the California Energy Commission's *2015 Integrated Energy Policy Report* (*2015 IEPR*). The off-road vehicles and equipment sectors covered by this study are:

- Airport ground support equipment.
- Forklifts.
- Plug-in hybrid work trucks.
- Transport refrigeration units.
- Port cargo handling equipment.
- Shore power.
- Truck stop electrification.

For most off-road sectors, there is more than one type of vehicle or equipment. In some sectors, *equipment* refers to ship berthings or parking spots. Appendix A lists the vehicles and equipment analyzed in this report for each off-road sector.

The method applied in this analysis estimates the total fleet population, the percentage of fleet projected to be electrified, and the average annual electricity usage per vehicle for each sector listed above. From these values, the total electricity usage for each sector can be calculated. In addition, the avoided fossil fuel (diesel or gasoline) use resulting from a switch to electricity is estimated. All the off-road vehicles and equipment covered in this study use diesel either exclusively or predominantly, except for forklifts. The non-electric forklift population is predominantly gasoline fueled.

The off-road demand forecasts include three cases – low, mid, and high – to be consistent with the corresponding cases of the Energy Commission's electricity demand forecast. In this report, the mid case is intended to be the most likely estimate for electricity usage. The low and high cases do not represent a lower and upper limit on electricity usage. The low case assumes a modest increase in electrification over present levels, falling short of levels expected from planned activity or expectations of stakeholders. The high case, in contrast, assumes electrification beyond expected levels, potentially resulting from new regulations, new financial studies showing stronger-than-expected return on investment, or owners' desire for a greener image.

Fuel-Switching Opportunities

In each of the off-road sectors considered in this study, there is either increasing electrification of the vehicle/equipment population or plans to electrify fleets. For some vehicles and equipment, the cost to own and operate electric vehicles (EV)/equipment may be lower than the cost of petroleum-fueled vehicles/equipment and would be the driver for fuel switching. In other cases, existing or expected future regulations will drive owners to electrify their fleets.

Fuel-switching opportunities for each off-road segment are discussed below. This study does not evaluate the economics of fuel switching, nor does it apply a consumer choice model to fuel-switching decisions. Rather, the discussion is qualitative.

Airport Ground Support Equipment

Ground support equipment (GSE) includes tugs, loaders, tractors, forklifts, and other equipment used at California airports to transport cargo, luggage, people, fuel, and miscellaneous items on the airport grounds. There is already significant electrification of GSEs at California airports. A Los Angeles World Airports study compared the annual cost of ownership of petroleum-fueled GSE with electric GSE and found significant potential cost savings for electric GSE.[1] In fact, Los Angeles International Airport (LAX) expects to fully electrify its fleets, while Ontario International Airport is 100 percent electrified. Since fuel switching has both environmental and economic benefits, airports are likely to increase the electrification of GSE.

Forklifts

Forklifts are used in industrial, agricultural, and commercial establishments to move heavy loads. Recent forklift sales data from the Industrial Truck Association Market Intelligence report appears to show a slight trend toward increased purchases of electric forklifts over conventionally fueled forklifts.[2] There are several factors involved in choosing a forklift. Electric forklifts generally have a longer life, are quieter, and operate with lower emissions, but they have lower power than the largest conventionally fueled forklifts. If high power is a requirement, electrification may not be an option for the heavier forklifts. Overall, owners must understand their particular needs and operating parameters to determine if electric forklifts can save money. If noise or emissions in an enclosed area are problematic, electric forklifts may be worth a higher cost.

Forklifts can operate on diesel, gasoline, or electricity and are classified by fuel source and size. Class 1 (electric motor rider trucks), Class 2 (electric motor narrow aisle

1 CDM Smith. 2015. *Extremely Low Emission Technology Ground Support Equipment Feasibility Study Report – Updated*. Prepared for the Los Angeles World Airports. http://www.lawa.org/uploadedFiles/LAX/pdf/LAX-eletGSE-Feasibility-Study-Report.pdf.

2 Industrial Truck Association. *Market Intelligence Forklift Report*. http://www.indtrk.org/wp-content/uploads/2013/04/US-Factory-Shipments-Through-2012.pdf.

trucks), and Class 3 (electric motor hand trucks or hand/rider trucks) operate on battery power. Classes 4 and 5 (internal combustion engine trucks) operate on diesel or gasoline. Presently, the industry operates a large fleet of Class 1-3 trucks, which consume electricity when recharged. When Class 4 or 5 forklifts are replaced, some of the new forklifts will likely be Class 1-3.

Utility Work Trucks

Utility work trucks are used to help perform maintenance or installation activities at electrical work sites. These work trucks can be electrified with battery packs to provide electric power. When trucks reach the site, the diesel engine will shut off, and all power needs are supplied by the battery pack. The packs are later recharged when the trucks are parked at the end of the work day. This report considers only the effect of electrification at work sites while the trucks are stationary. The Edison Electric Institute led a study to determine the benefits of electrifying utility vehicle fleets.[3] In particular, the study estimated the ownership costs for conventional bucket trucks compared to electrified trucks with a battery pack. Depending on the actual parameters of operation (hours per day at the work site, diesel and electricity usage per hour, the cost of diesel fuel and electricity), electrified work trucks are potentially cost effective.

There are significant additional benefits of electrifying the work truck fleet. Diesel generators produce unpleasant fumes for workers who must stay close to the truck for hours. Noise regulations prevent diesel generators from operating late in the evening; electric power would allow crews to continue working much later at night. Some utilities nationwide have pledged to use 5 percent or more of their vehicle funding toward electrified vehicles to potentially save money and encourage other companies and individuals to purchase plug-in EVs, thereby increasing utility revenues by raising electricity usage.[4]

Transport Refrigeration Units

Transport refrigeration units (TRU) are refrigeration systems (powered by integral diesel engines) to protect perishable goods in transit. Some truck owners have purchased electric TRUs (eTRU) to plug in to the grid when parked at appropriate locations. While the capital cost for an eTRU is higher than a conventional TRU, a 2005 Shore Power study concluded that the payback period could be less than one year for a 10 percent incremental cost and less than two years for a 30 percent incremental cost.[5] A California

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3 Edison Electric Institute. 2014. *Transportation Electrification: Utility Fleets Leading the Charge.* http://www.eei.org/issuesandpolicy/electrictransportation/fleetvehicles/documents/eei_utilityfleetsleadingthecharge.pdf.

4 Edison Electric Institute. 2014. *Transportation Electrification: Utility Fleets Leading the Charge.*

5 Tario, Joseph. 2005. *Electric-Powered Trailer Refrigeration Unit Market Study and Technology Assessment, ShurePower.* Prepared for The New York State Energy Research and Development Authority. http://www.shorepower.com/adeq-nyserda-final-report.pdf.

Air Resources Board (ARB) technology assessment estimates conversion costs for electric trailer refrigeration units to be roughly $10,000 to $13,000 with potential operating savings of roughly $3,900 to $5,800 per year.[6] ARB is considering phased regulations closer to 2020 to prohibit the use of fossil-fueled transport refrigeration units for cold storage.[7] This regulation may push additional purchases of eTRUs.

Port Cargo Handling Equipment

While electrified port equipment is not yet common, port personnel at the Ports of Long Beach and Los Angeles indicated that the ports have a goal of electrifying much of the cargo-handling equipment (CHE). The ports could do a study similar to the one performed by the Los Angeles World Airports to determine the economic feasibility of electrified forklifts, yard tractors, and rubber-tired gantry (RTG) cranes. Depending on the parameters of operation, some locations could potentially benefit from switching to electric operation.

Ports often operate in very unhealthy environments due to the large number of ships, CHE, and drayage trucks emitting significant pollution. State and local air quality agencies, such as ARB and South Coast Air Quality Management District, have continually worked with the ports to reduce their emissions. Regulations could be imposed to hasten the transition to electric equipment. The ports are well aware of their environmental footprint and feel the pressure to lower emissions.

Shore Power

ARB approved the Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port regulation (At-Berth Regulation) in December 2007. The At-Berth Regulation requires container, cruise, and reefer ships to use shore power or some alternative method that reduces emissions.[8] Shore power is the provision of electrical power to a ship docked at berth while the main and auxiliary engines are shut down. Such power would be generated onshore using resources with lower emissions than the diesel engines onboard docked ships. The requirement will increase to cover 80 or 90 percent of all ship visits by 2020, depending on whether a port has received funding from the 2006 Highway and Port Safety and Air Quality Bond Act. To support the potential volume of ships with shore power, ports must modify their infrastructure to be able to supply grid power whenever needed.

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6 California Air Resources Board. 2014. *Transport Refrigerators: Technology Assessment.* http://www.arb.ca.gov/msprog/tech/presentation/tru.pdf.

7 California Air Resources Board. 2015. *Sustainable Freight: Pathways to Zero and Near-Zero Emissions.* http://www.arb.ca.gov/gmp/sfti/sustainable-freight-pathways-to-zero-and-near-zero-emissions-discussion-document.pdf.

8 California Code of Regulations, Title 17, Section 93118.3, and California Code of Regulations, Title 13, Section 2299.3

Should ports not complete these modifications on time, the conversion rate of ships using shore power could be slowed.

Truck Stops

Anti-idling regulations prevent trucks from idling for significant periods when parked. Trucks can either use auxiliary power units (APU) or electrify cabins to allow grid connections at truck stops when they park. There are relatively few electrified parking spaces, so unless a truck is in one of those preferred locations, the owner cannot use grid power. Truckers have to weigh the benefits of quiet, low-operating-cost electrification with the lower capital cost of diesel APUs and the low availability of electrified parking spaces.

Report Organization

The remainder of the report is organized into the following topics:

Existing Studies and Models

- **Review of Previous California Electrification Forecasts**

  Three previous reports estimated electricity usage for off-road vehicles and equipment. This chapter reviews each study and discusses differences among them and the present study.

- **California Air Resources Board Off-Road Models**

  ARB maintains several models that are used to calculate its emissions inventories. The off-road sectors considered in this report are covered in three of these models. The models are briefly described, and the value of these models to this study is discussed.

Method

- **Electricity Demand Macroeconomic Assumptions**

  Economic growth can affect vehicle demand and fuel use. Macroeconomic assumptions for the period 2015 through 2026 are identified and the related effect on the forecasts described.

- **Fuel-Switching Opportunities**

  Each vehicle sector contains opportunities for vehicle owners to purchase new technologies that can electrify the fleet. Owners make vehicle choices based on several factors. This section discusses potential fuel choice models that could be created to better predict transitions to electrification.

- **Off-Road Vehicle Electrification Forecast**

  This chapter details the off-road vehicle electrification forecast for each sector, describes the general method used to forecast electricity usage, and identifies the sources for projected fleet populations and vehicle fuel use.

CHAPTER 2: Existing Studies and Models

This chapter reviews three reports that address off-road vehicle electrification in California. These reports, completed between 2005 and 2014, include:

- *Electric Transportation and Goods Movement Technologies in California: Technical Brief (Tiax).*[9]
- *California Transportation Electrification Assessment.*[10]
- *California Energy Demand 2014 – 2024 Final Forecast.*[11]
- *California Air Resources Board Off-Road Models.*[12]

Electric Transportation and Goods Movement Technologies in California: Technical Brief

The 2005 Tiax study (updated in 2008) estimated potential benefits and impacts from electrification in a wide variety of markets. The method generally consisted of estimating the total number of vehicles, the annual activity in hours, and the vehicle average power to estimate the total electrical energy usage. The markets included:

- Non-road EVs (forklifts, airport GSE, golf carts, sweepers, scrubbers, burnishers, industrial tow-tractors, personnel carriers, and turf trucks).
- Battery EVs, city EVs, neighborhood EVs, and plug-in hybrid EVs.
- Shore power.
- Truck stop electrification.
- Transport refrigeration units.
- Port CHE.

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9 Tiax LLC. 2008. *Electric Transportation and Goods Movement Technologies in California: Technical Brief.* Report for California Electric Transportation Coalition. http://www.arb.ca.gov/regact/2009/lcfs09/tiax.pdf.

10 ICF International. 2014. *California Transportation Electrification Assessment Phase 1: Final Report.* http://www.caletc.com/wp-content/uploads/2014/09/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf.

11 California Energy Commission. 2014. *California Energy Demand 2014-2024 Final Forecast, Volume 1: Statewide Electricity Demand, End-User Natural Gas Demand, and Energy Efficiency.* California Energy Commission, Electricity Supply Analysis Division. Publication Number: CEC-200-2013-004-V1-CMF. http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC-200-2013-004-SF-V1.pdf.

12 Models and documentation can be found on the ARB website at http://www.arb.ca.gov/msei/categories.htm.

- Electric lawn and garden equipment.
- Hydrogen fuel production for fuel cell and hydrogen internal combustion vehicles.

The study calculated criteria pollutant and greenhouse gas (GHG) reductions and petroleum fuel displaced by the new electric technologies. The base year is 2002, and the forecast runs through 2020 with outputs generated for 2010, 2015, and 2020. The study created two cases – an “expected market” case and an “achievable market” case.

- The *expected market case* was determined by extrapolating the effects of natural market growth, incentive programs, and regulations on current trends in the market.
- The *achievable market case* assumed aggressive incentive programs and regulations. Some markets reach very high penetration levels, while others remain at low levels.

In the achievable market case, technologies such as electric golf carts, sweepers/scrubbers, and forklifts reach 95 percent market share by 2020, but battery EVs, city EVs, and neighborhood EVs only achieve very low levels of market penetration.

California Transportation Electrification Assessment

ICF completed the *California Transportation Electrification Assessment* (*CalTEA*) study for the California Electric Transportation Coalition in 2014. The *CalTEA* updates and adds to the earlier Tiax study and includes more recent population data and forecast results through 2030. It adds new sectors such as medium- and heavy-duty vehicles, rail, and catenary trucks. The study also includes a cost analysis of certain electrification technologies, identifies gaps, and examines barriers for plug-in vehicle adoption.

Similar to the Tiax study, the *CalTEA* study reports results for electricity usage, petroleum displacement by electric technologies, and criteria pollutant and GHG reductions from electrification. The *CalTEA* study uses essentially the same method as the Tiax study and often uses the same input data for fuel consumption and fuel efficiency.

While the Tiax study created two cases, the *CalTEA* study defines three cases – “In line with current adoption,” “Aggressive adoption,” and “In between.”

- The “In line with current adoption” case is based on expected market growth, expected incentive programs, and existing regulations. This case is essentially a lower limit on electrification.
- The “Aggressive adoption” case includes aggressive incentive programs and regulations. While this case does not represent the maximum potential electrification, it essentially assumes that everything that could reasonably increase movement towards adopting electric technologies will happen.

- The "In between" case falls between the other cases and often is the midpoint between the two.

The study presented here (Aspen study) is similar to the *CalTEA* study. The method in the Aspen study is similar to that of the *CalTEA* study; however, the Aspen study excludes some sectors covered in the *CalTEA* study, such as battery and plug-in EVs, rail, lawn and garden equipment, sweepers, personnel carriers, golf carts, and turf trucks. In contrast, the Aspen study includes plug-in utility work trucks, which the *CalTEA* study leaves out.

California Energy Demand 2014–2024 Final Forecast

The *2014 California Energy Demand (2014 CED)* forecast covers 2014 through 2024.[13] The forecast covers all electricity sectors, including residential, commercial, industrial, and agricultural, as well as transportation, communication, and utilities (TCU). The report estimates electricity demand, peak electricity, and natural gas demand for the state and relevant planning areas.

The forecast creates three cases – high energy demand, low energy demand, and mid energy demand. The high energy demand case assumes relatively high economic and demographic growth, low electricity and gas rates, and a relatively low committed efficiency program. The low energy demand assumes lower economic and demographic growth, high electricity and gas rates, and a higher committed efficiency program. The mid case assumes values between the high and low case.

The *2014 CED* includes electricity demand for all sectors of the economy and focuses on major drivers of the economy. More specifically, it includes a transportation electricity demand forecast for EVs and high-speed rail. Furthermore, the *2014 CED* report includes demand forecast for port shore power, forklift, and other off-road vehicle and equipment that are generated by the TCU sector model, as well as other sector models. The Aspen study defines the cases in the same way as the *2014 CED* and uses the same input data as the *2014 CED*, but is focused on electrification data for the off-road sector that relate mostly to the electricity demand generated for TCU, including shore power and other sectors listed earlier.

California Air Resources Board Off-Road Models

The ARB uses four models to calculate the emissions inventory information relevant to off-road vehicles. These models include the off-road emissions inventory, Cargo Handling Emissions Inventory (CHEI) model, Marine Emissions Model, and TRU model.[14]

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13 California Energy Commission. 2014. *California Energy Demand 2014-2024 Final Forecast, Volume 1: Statewide Electricity Demand, End-User Natural Gas Demand, and Energy Efficiency*. California Energy Commission, Electricity Supply Analysis Division. Publication Number: CEC-200-2013-004-V1-CMF. http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC-200-2013-004-SF-V1.pdf.

14 Models and documentation can be found on the ARB website at http://www.arb.ca.gov/msei/categories.htm.

All four models use the Microsoft Access® platform. **Table 1** shows the off-road equipment covered in the four ARB inventory models that are relevant to this study.

Table 1: ARB Emissions Inventory Models and Associated Off-Road Equipment

ARB Inventory Model	Associated Equipment
1. Off-road emissions inventory model	Forklifts (diesel and gasoline) Airport GSE (primarily diesel)
2. CHEI model	Port CHE (primarily diesel)
3. TRU model	TRUs (primarily diesel)
4. Marine emissions model	Shore power (primarily diesel)

Source: California Air Resources Board. *Emissions Models and Documentation.* http://www.arb.ca.gov/msei/categories.htm

The four ARB emissions inventory models listed in **Table 1** were created to estimate emissions for various classes of vehicles or equipment. Because of this, these models include many inputs necessary for electrification usage calculations. The inventory models contain population data extrapolated to 2026, activity as a function of equipment age in hours per year for the vehicles or equipment, and load factors.

All four of the emissions inventory models were last updated in 2011, but some of the inputs are taken from older data sets or reports. Accordingly, this study often used more recent data for populations, projections, and fuel economy from other sources. The ARB emissions inventory models also do not model plug-in utility work trucks and truck stops.

This study used the ARB's TRU and CHEI models for TRU and port CHE fleet population projections through 2026. Data for energy usage for TRUs and port CHE were found from more recent reports or through discussions with experts. For all the other off-road vehicle markets in this study, populations, projections, and fuel economies were found from more recent sources that are documented in later chapters of this report.

The ARB uses another model, known as "Vision," to calculate emissions. The 2012 version, known as "Vision 2012," has fewer off-road equipment sectors than the emissions inventories, and ARB uses the emissions inventories to estimate emissions from off-road sources.[15] The only sectors relevant to this study in Vision 2012 are port CHE and ocean-going vessels. ARB recently released a new version of this model, known as "Vision 2.0."[5] The off-road module includes airport GSE and forklifts. The oceangoing vessel module includes shore power. The off-road module forecasts through 2050, and the oceangoing vessel module forecasts through 2031. Vision 2.0 is available only as a limited scope release.

15 Model and documentation can be found on the ARB website at http://www.arb.ca.gov/planning/vision/downloads.htm.

CHAPTER 3: Method

This forecast uses estimates of the total fleet population, the proportion of fleet electrification, and the average annual electricity usage per vehicle. The data to develop these forecasts come from of a variety of source material, from state and national agency reports, to research papers and discussions with experts. In some instances, the source material points to a relatively clear set of cases where the percentage of vehicle electrification can be estimated with some confidence. In other instances, there is not enough information to develop robust estimates for the low and high cases; therefore, rough estimates are based on discussions with experts or consideration of projections from reports must be used. The method is described below.

Demand Cases

This off-road vehicle electrification demand forecast includes a low, mid, and high demand case to be consistent with the *California Energy Demand 2016-2026, Revised Electricity Forecast, Volume 1: Statewide Electricity Demand and Energy Efficiency*.[16] The low and high demand cases do not represent a lower and upper limit on electricity usage. Instead:

- The mid case represents adoption of EVs that appears most likely.
- The low demand case assumes electrification regulation will be met by a modest increase in electrification over present levels.
- The high demand case assumes aggressive electrification. In this case, regulation requiring electrification could be introduced where it presently does not exist, or fleet electrification could accelerate due to more favorable economics or an expansion of environmentally favorable programs.

The demand cases are essentially determined by the percentage of fleet electrification. Rather than attempt to estimate the percentage year by year out to 2026, values for this percentage were estimated only for 2026. Fleet penetration was then assumed linear from 2015 through 2026, with an equal percentage added every year.

Estimation Methods

The method to estimate the electricity demand and avoided diesel and gasoline usage is similar for each off-road sector. This method is described below.

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16 California Energy Commission. 2016. *California Energy Demand 2016-2026, Revised Electricity Forecast, Volume 1: Statewide Electricity Demand and Energy Efficiency*. California Energy Commission. Publication Number: CEC-200-2016-001-V1. http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-01/TN210527_20160224T115023_2015_Integrated_Energy_Policy_Report__Small_Size_File.pdf.

Estimate Fleet Stock (N)

For each vehicle and equipment type within a sector, the authors estimate the present number of vehicles and equipment in the fleet. That fleet stock for each vehicle or equipment type is then projected out each year to 2026 based on macroeconomic projections for the California gross state product (GSP).

Estimate Percentage of Vehicle Electrification (%elec)

To determine the number of potential electrified vehicles, the percentage of electrified vehicles (%elec) is estimated for each vehicle and equipment type. The %elec is estimated based on present regulations where applicable, discussions with stakeholders, and studies or reports showing potential costs and benefits of electrification plans. The percentage is estimated for each year out to 2026.

Calculate Electrified Fleet (N_e)

The number of vehicles in the fleet that use electricity is then calculated by:

$$N_e = N*\%elec$$

Where N is the total population of vehicles and equipment in each sector. N_e is calculated for each vehicle type and each year through 2026. As with certain fleets, N_e may not be an actual number of vehicles. For the case of shore power, N_e is the number of berthings using electric power.

Calculate Electricity Usage per Year (Elec Usage)

For each vehicle type, the total electricity usage for the year is calculated. This calculation is done in varying ways. If the vehicle activity (Hours) and vehicle average power (P) demand are known, then the electricity usage per year for a given vehicle can be calculated. Sometimes instead of activity and power, the total energy usage per year (E_{yr}), as for airport CHE, or per day (E_{day}), as for work trucks, is known. The relevant equations are:

$$\text{Elec Usage} = N_e*\text{Hours}*P$$

$$\text{Elec Usage} = N_e*E_{yr}$$

$$\text{Elec Usage} = N_e*E_{day}*\text{Total Days}$$

Calculate Avoided Fuel Use per Year (Gal_A)

The avoided fuel use is the petroleum fuel (usually diesel) that would have been used by the vehicles that were replaced by electrified vehicles since 2015. The number of vehicles replaced by electrified vehicles ($N_{replaced}$) is calculated as the number of electrified vehicles in a given year minus the number of vehicles in 2015. The avoided fuel per year is then the number of replaced vehicles multiplied by the annual conventional fuel use per vehicle. For some sectors, the data directly give Gal/yr rather than Gal/hour and total hours. In that case, the second equation is used.

$$Gal_A = N_{replaced} * hours * Gal/hour$$

$$Gal_A = N_{replaced} * Gal/yr$$

In some instances, the avoided fuel is gasoline. In those instances, the avoided fuel is calculated both in gallons of gasoline avoided and in gallons of diesel fuel equivalent.

Once the electricity usage and gasoline and diesel fuel avoided are calculated, the values are summed for each vehicle type in each sector to yield the total electricity usage and avoided fuel equivalent for that sector.

Input Sources and Assumptions

Using the method, different sources of input data and assumptions were used to generate forecasts of electricity use and petroleum displacement for each off-road sector.

Macroeconomic Inputs and Assumptions

An important input in estimating electricity usage is the projected population of the vehicles and equipment to be electrified. There are several factors that could affect these populations, including macroeconomic growth; economic growth specific to a particular industry, such as air travel or port containers; or other relevant factors such as funds designated for upgrades to equipment.

The projected populations for the various vehicles or equipment included in this study rely on the low, mid, and high macroeconomic forecasts of 2016 to 2026 California GSP that are used in the *California Energy Demand Forecast* adopted as part of the *2015 IEPR*.[17] The projected annual increases in GSP for 2015 to 2026 are 2 percent, 2.3 percent, and 3 percent in the low, mid, and high demand cases, respectively. The vehicle and equipment populations for each off-road sector are first determined for the base year, 2015, and then projected through 2026 by escalating the 2015 numbers by the GSP growth rate in each demand case (low, mid, and high).

The effect of the variation of vehicle/equipment population on the forecast is small. The much bigger impact derives from the variation in the proportion of the fleet population assumed electrified. **Table 2** shows the assumed ranges of percentage electrification for each off-road sector considered in this study.

17 California Energy Commission. 2016. *California Energy Demand 2016-2026, Revised Electricity Forecast, Volume 1: Statewide Electricity Demand and Energy Efficiency*. California Energy Commission. Publication Number: CEC-200-2016-001-V1. \http://docketpublic.energy.ca.gov/PublicDocuments/15-IEPR-03/TN207439_20160115T152221_California_Energy_Demand_20162026_Revised_Electricity_Forecast.pdf.

Table 2: Percentage Electrification in 2026 by Off-Road Sector

Off-Road Sector	Case	
	Low	High
Airport GSE	25	45
Forklifts	0	25
Utility work trucks	40-49	67-73
TRUs	0-11	20-60
Port CHE	5-10	20-40
Shore power	80	90
Truck stops	2.5	40

Source: Aspen Team analysis

The Energy Commission's macroeconomic growth forecast varies by a few percentage points, but the estimate of percentage electrification varies by a much larger amount. The lowest variation is in the shore power percentage electrification where the high and low estimates differ by 10 percent. For some sectors, the variation is 40 percent or larger. Clearly, variations in percentage electrification dominate the uncertainty in the population of electrified equipment.

Technology-Specific Inputs and Assumptions

Different sources of inputs were used for different sector technologies, along with different sets of assumptions. This section details specifics of inputs and assumptions for each technology.

Airport Ground Support Equipment

Data for 2014 from an Airport Cooperative Research Program Report were used to estimate the number of pieces of CHE at United States (U.S.) airports.[18] Federal Aviation Administration enplanement data were used to scale the U.S. data to California.[19] Roughly 11 percent of U.S. enplanements (airplane boardings) occur in California. It is assumed that the CHE requirements for California are similar to those of all U.S. airports.

A recent report from the Los Angeles World Airports Environment and Land Use Planning Division considered the potential to electrify airport GSE.[20] Presently, roughly

18 Airport Cooperative Research Program. 2012. *Airport Ground Support Equipment (GSE): Emission Reduction Strategies, Inventory, and Tutorial.* ACRP Report 78. http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_078.pdf.

19 Federal Aviation Administration. Passenger Boarding (Enplanement) and All-Cargo Data for U.S. Airports. http://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger.

20 CDM Smith. 2015. *Extremely Low Emission Technology Ground Support Equipment Feasibility Study Report – Updated.* Prepared for the Los Angeles World Airports. http://www.lawa.org/uploadedFiles/LAX/pdf/LAX-eletGSE-Feasibility-Study-Report.pdf.

37 percent of LAX GSE is electrified. The report recommends that the majority of GSE equipment types be completely electrified to reduce emissions, although no timetable is given. An earlier report from the Los Angeles World Airports indicated that 100 percent of Ontario International Airport tenant GSE is electrified.[21] Additionally, the *CalTEA* reported that roughly 50 percent of GSE at San Jose International Airport is electrified.[22] Based on these data, it is estimated that roughly 20 percent of California GSE is electrified.

The Los Angeles World Airports Environment and Land Use Planning Division report used data from LAX to estimate the fuel costs for both diesel and electric GSE. The data include a yearly cost along with the assumed price of both diesel and electricity. Using these numbers, the estimated yearly fuel usage for each type of equipment was calculated. The fuel usage is shown in **Table 3**. The report compared capital and operating costs for diesel and electric GSE and concluded that in many cases, electric GSE is cost-effective. The costs came from 2015 data and were assumed constant over the period of cost calculation.

Table 3: Estimates for Airport GSE Fuel Use for Both Diesel and Electric Versions

GSE Type	Diesel Fuel (gallons/year)	Electricity (kWh/year)
A/C Tug Narrow Body	2,190	9,493
A/C Tug Wide Body	2,190	9,493
Baggage Tug	2,190	10,280
Belt Loader	1,095	4,207
Cargo Tractor	2,190	10,280
Forklift	1,460	8,540
Lift	2,190	9,493
Passenger Stand	2,190	10,280
Other GSE	1,643	7,247

Source: Los Angeles World Airports. 2008. *Los Angeles World Airports Sustainability Plan*.

The GSE type “other” includes cargo loaders, carts, hydrant carts, lavatory carts, and sweepers.

Based on the relatively high percentage of electrification at certain airports and the cost results from the Los Angeles World Airports report, it is assumed that California airports will move to electrify a significant percentage of the airport GSE. The assumptions for the three cases are given in **Table 4**.

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21 Los Angeles World Airports. 2008. *Los Angeles World Airports Sustainability Plan.* https://www.lawa.org/uploadedFiles/LAWA/pdf/Sustainability%20Plan%20%28Final%29.pdf.

22 *ICF International. 2014. California Transportation Electrification Assessment Phase 1: Final Report.* http://www.caletc.com/wp-content/uploads/2014/09/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf.

Table 4: Assumptions for Percentage Electrification of GSEs at California Airports

Case	2015	2026
Low	20	30
Mid	20	40
High	20	50

Source: Aspen team analysis

Forklifts

Forklift sales data were taken from an Industrial Truck Association Market Intelligence report showing factory shipments for forklifts in the United States from 1990 through 2012.[23] The sales are broken into three groups – Classes 1 and 2 (electric rider), Class 3 (motorized hand electric), and Classes 4 and 5 (internal combustion engine). Using an estimate of forklift lifetimes from the *CalTEA* study for electric and internal combustion at 8 and 7 years, respectively, along with the sales data, the authors calculated an estimate for the 2013 fleet size for each class. The fleet sizes for California were estimated by assuming forklift sales mirror state populations and used 12 percent as the percentage of U.S. population in California.

Macroeconomic projections of California GSP are used to forecast forklift populations through 2026 for Classes 1-3. Classes 4 and 5 fleet projections assume that the percentage of internal combustion forklifts to total forklifts stays constant at 45 percent.

The low case assumes forklift sales consistent with the historical sales described above. This assumption reflects the reality that better data are not available. The mid and high cases assume that a percentage of projected purchases of Classes 4 and 5 forklifts will shift to purchases of Class 1, 2, or 3 and be electric. There is some indication from sales data that the percentage of internal combustion engine forklifts has decreased since 2007 from 45 percent of the total to roughly 35 percent. That trend would indicate that 20 percent fewer internal combustion engine forklifts have been sold recently. The mid and high cases assume that 15 percent and 25 percent, respectively, of Classes 4 and 5 forklifts will be purchased as Class 1 or 2 forklifts by 2026.

Both Classes 1 and 2 electric forklifts can be "low" power (6,000-8,000 lbs) or "high" power (19,800 lbs), and Classes 4 and 5 internal combustion forklifts can be both gasoline-powered (< 120 horsepower [hp]) or diesel-powered (> 120 hp). To determine the electricity usage and avoided diesel-gallon-equivalent fuel in the forecast from shifting sales from Classes 4 and 5 internal combustion engine forklifts to electric forklifts, the authors assumed that gasoline forklifts would shift to electric forklifts in the Classes 1 and 2 low-power electric forklifts, and diesel forklifts would shift to

23 Industrial Truck Association. *Market Intelligence Forklift Report*. http://www.indtrk.org/wp-content/uploads/2013/04/US-Factory-Shipments-Through-2012.pdf.

Classes 1 and 2 high-power electric forklifts. All forklifts originally projected as Classes 1 and 2 are assumed to be low power. The ARB forklift populations show roughly 86 percent of Classes 4 and 5 internal combustion forklifts are gasoline-powered, and roughly 14 percent of Classes 4 and 5 internal combustion forklifts are diesel-powered. Finally, the *CalTEA* estimates that low-power Classes 1 and 2 electric forklifts use 18.3 megawatt hours (MWh)/year, high-power Classes 1 and 2 electric forklifts use 52.8 MWh/year, and Class 3 forklifts use 5.2 MWh/year. The avoided fossil fuel use is calculated by using the electrical energy from the electric forklifts and assuming 0.24 gallons of gasoline/kilowatt hour (kWh) and 0.16 gallons of diesel/kWh.

Plug-In Hybrid Work Truck

Work truck electricity usage was estimated for the California utilities, Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Sacramento Municipal Utility District (SMUD), and San Diego Gas & Electric Company (SDG&E).[24] Recently, PG&E began a significant program to electrify its entire fleet. The utility believed that transitioning to electrified vehicles could give it a positive greener image, save money due to reduced fuel costs, and encourage consumers and industry to take similar steps to purchase plug-in or electric vehicles, thus increasing overall electricity usage. It began working closely with companies that manufactured plug-in work trucks and started to aggressively purchase these vehicles to replace conventional diesel trucks. In addition, it initiated a program with utilities across the United States to voluntarily use 5 percent of its vehicle purchase funds to buy plug-in electric vehicles (PEV).

California utilities were contacted to get information on their present bucket truck fleets and assess expected future PEV purchases. Bucket trucks come in two sizes – 37’ and 55’ – with fleets generally having about twice as many small bucket trucks as large ones. PG&E already has a large fleet of PEV bucket trucks and fully expects to electrify the entire fleet by 2026. Both the mid and high cases assume PG&E will reach 100 percent electrification by 2025. The low case assumes it does not meet its goal and falls short by roughly 20 percent. SCE presently has a few electrified trucks but will purchase 35 PEV trucks this year. Based on rough projections for future purchases, the low, mid, and high cases assume 10, 20, and 30 purchases of PEVs per year, respectively, through 2026. In the high case, the percentage of PEV bucket trucks reaches almost 50 percent by 2026. Future PEV purchases for both SMUD and SDG&E were assumed to be similar to SCE as a percentage of total trucks for all cases.

The fleets were assumed to grow at the same rate as macroeconomic projections for the California GSP through 2026. A recent study by the Edison Electric Institute reviewed the economics of electrified work trucks and gives information relevant to electricity

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24 Sufficient data to estimate electricity usage for LADWP were not available.

and diesel fuel usage for bucket trucks at work sites.[25] **Table 5** summarizes this information.

Table 5: Data for Electricity and Diesel Fuel Usage for Utility Bucket Trucks

Fuel & Usage Assumption	**Truck Size**		**Units**
	37'	**55'**	
Electricity used/day	5	8	kWh
Diesel consumption/hour	0.8	1.2	gal/hour
Hours idle/day	4	4	hours
Diesel avoided/day	3.2	4.8	gallons
Days/year	260	260	Days

Source: Edison Electric Institute. 2014. *Transportation Electrification: Utility Fleets Leading the Charge.*

Transport Refrigeration Units

TRUs are refrigeration systems (powered by integral diesel engines) to protect perishable goods transported in insulated truck and trailer vans, rail cars, and domestic shipping containers. The 2015 TRU fleet population and mid-case projection for the TRU fleet population through 2026 were taken from the ARB TRU emissions inventory database.[26] TRU fleet population projections for the low and high cases were constructed using California GSP projections for the low, mid, and high cases. The ratio of the low to mid fleet populations is set equal to the ratio of the low to mid GSP projections. Similarly, the ratio of the high to mid fleet populations is set equal to the ratio of the high to mid GSP projections.

The database includes four classes of TRUs: < 11 hp, 11-25 hp, > 25 hp, and out-of-state. The out-of-state TRUs are assumed to all be large or > 25 hp. The hours of operation come from the emissions inventory database. Use of eTRUs is possible only when the truck is parked at a location where the eTRU may be plugged in. There is significant variation in the percentage of operating hours when an eTRU may be plugged in, and the average is taken as 30 percent.

While there is presently no regulation to shift diesel TRUs to eTRU that can be plugged in while the truck is stationary, ARB may limit the time a stationary truck may use a diesel TRU to less than eight hours. Given that trucks may sit for extended periods on weekends waiting for Monday dispatch, owners could then opt to install eTRUs. There

25 Edison Electric Institute. 2014. *Transportation Electrification: Utility Fleets Leading the Charge.* http://www.eei.org/issuesandpolicy/electrictransportation/fleetvehicles/documents/eei_utilityfleetsleadingthecharge.pdf.

26 California Air Resources Board. *TRU ISOR Appendix C.* http://www.arb.ca.gov/regact/2011/tru2011/truisor.pdf.

are no clear indications of the percentage of diesel TRUs that might be electrified by 2026; in discussions with ARB staff, suggestions were made that the electrification percentages, for the three cases in **Table 6** are reasonable.[27] Out-of-state trucks would have no clear reason to convert to eTRUs especially given that very few locations likely would exist outside California to plug into the grid. Only the high case includes any electrification of out-of-state TRUs.

Table 6: Assumed TRU Electrification Percentage by 2026

TRU Size	Low	Mid	High
< 11 hp	11	40	50
11 – 25 hp	11	50	60
> 25 hp	11	25	50
Out-of-state	0	0	20

Source: California Air Resources Board TRU emissions inventory database for mid case, and Aspen Environmental Group for low and high cases.

The electricity and diesel fuel usage for operating eTRUs and TRUs is taken from the *CalTEA* and discussions with ARB personnel.[28] The values are given in **Table 7** and assumed constant through 2026.

Table 7: Electricity and Diesel Fuel Usage for TRUs (per Hour)

TRU Size	Electric Power (kW)	Diesel Use (gal/hour)
< 11 hp	2.3	0.21
11 – 25 hp	6	0.62
> 25 hp	10	0.85
Out-of-state	10	0.85

Source: ICF International. 2014. *California Transportation Electrification Assessment Phase 1: Final Report.*

Port Cargo Handling Equipment

The fleet populations for 2015 for CHE on California ports are taken from the ARB's CHE emissions inventory model.[29] The fleets were assumed to grow at the same rate as macroeconomic projections for the California GSP through 2026. Three equipment types are included – yard tractors, port forklifts, and RTG cranes. The inventory model gives activity in hours per year for each equipment type. The recent widening of the Panama

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27 Private communication with Rodney Hill at the California Air Resources Board.

28 ICF International. 2014. *California Transportation Electrification Assessment Phase 1: Final Report.* http://www.caletc.com/wp-content/uploads/2014/09/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf.

29 http://www.arb.ca.gov/ports/cargo/cheamd2011.htm.

Canal could affect container traffic at Southern California ports, since larger ships will be able to travel through the canal. There is speculation that East Coast ports could pick up container ship volume at the expense of West Coast ports, but the actual effect is difficult to estimate since there are competing factors. Ships are growing larger, and the largest ships will still be too big to traverse the Panama Canal. The real question may focus on which ports can accept the larger ships. (West Coast ports have the ability to accept larger ships). According to Dr. Noel Hacegaba, managing director of commercial operations and chief commercial officer, Port of Long Beach,

> [F]rom our perspective, the real game is not Panama Canal expansion. Our perspective is that it is the growing size of vessels that will have the greatest impact on our port facilities and traffic.[30]

If the larger vessels berthing at Southern California ports in the future can deliver an increasing number of containers, these ports will not be significantly affected by the canal.

No regulation exists that would offer incentives for or mandate purchasing electric CHE on the ports. Discussions with the Port of Long Beach and Port of Los Angeles personnel indicated that the ports have a goal of reducing emissions to zero, but the time frame is not specified. Electric versions of forklifts, tractors, and cranes do exist, and the expectation is that the ports will begin to electrify their fleets.

Electrifying RTG cranes is not a straightforward procedure. The region of the port that would contain the electric cranes must be reconfigured before electric cranes are purchased and installed. In 2008, the Port of Long Beach offered to pay 50 percent of the cost of electrification, but no operators chose to convert. **Table 8** shows the assumed electrification percentages for the three cases.

Table 8: Percentage Electrification of Port CHE in 2025 by Equipment Type and Case

	Case		
Port Equipment	**Low**	**Mid**	**High**
Forklift	10	20	40
RTG Crane	5	10	20
Yard tractor	10	20	40

Source: Aspen Team analysis

The electrical power of port CHE is taken from a 2012 Tiax study.[31] Tractors, forklifts, and RTG cranes use 24, 5.8, and 52 kilowatt (kW), respectively. This load is assumed constant during the equipment activity.

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30 2014. “West Coast Ports Prepare for the Future.” *Pacific Maritime Magazine*, Vol. 32, No. 05. http://www.pacmar.com/story/2014/05/01/features/west-coast-ports-prepare-for-the-future/238.html?m=true

Shore Power

The shore power forecast is based on container, cruise, reefer, and tanker ship visits to California ports. Data for tanker and container ship visits come from the U.S. Department of Transportation Maritime Administration.[32] The data include ship visits for the ports of Long Beach, Los Angeles, Hueneme, San Diego, and the San Francisco Bay Area. Cruise ship visit data comes from Energy Commission estimates for ports of Long Beach, Los Angeles, Hueneme, San Diego, and San Francisco. Reefer ship data comes from the Port of Hueneme. The ship visits were assumed to increase at the same rate as macroeconomic projections for the California GSP through 2026.

ARB regulates container, cruise, and reefer ship visits to the ports of Long Beach, Los Angeles, Hueneme, San Diego, Oakland, and San Francisco. At-Berth Regulation requires fleets to meet 50 percent shore power electrification requirements by 2014, 70 percent by 2017, and 80 percent by 2020.[33] Berths that received funding from the 2006 California Highway and Port Safety and Air Quality Bond Act must meet 60 percent shore power electrification requirements by 2014, 80 percent by 2017, and 90 percent by 2020. Ships may use alternative control techniques that achieve equivalent emissions reductions. The assumptions for electrification percentages for ship visits in are shown in **Table 9**.

Table 9: 2026 Electrification Percentages for Ship Visits by Case

Year	Electrification Percentage		
	Low Demand Case	Mid Case	High Demand Case
2015	50	50	50
2026	80	85	90

Source: Aspen team analysis

Data from the *2011 Port of Long Beach Emissions Inventory* are used for the average berth times and electrical load for each ship type.[34] The berth times, electric load, and total energy per berth are shown in **Table 10**. It is assumed that these values do not

31 Tiax LLC. 2012. *Roadmap to Electrify Goods Movement Subsystems for the Ports of Los Angeles and Long Beach.* Consultant Report by TIAX LLC for the Ports of Los Angeles and Long Beach.

32 U.S. Department of Transportation Maritime Administration. 2013. *Vessel Calls in U.S. Ports and Terminal.* http://www.marad.dot.gov/wp-content/uploads/pdf/DS_U.S.-Port-Calls-2013.pdf.

33 California Code of Regulations, Title 17, Section 93118.3 and California Code of Regulations, Title 13, Section 2299.3.

34 Starcrest Consulting Group, LLC. 2012. *Port of Long Beach Air Emissions Inventory 2011.* http://www.polb.com/civica/filebank/blobdload.asp?BlobID=10194.

change during the forecast. The diesel fuel avoided is calculated by assuming the large ship diesel engines are roughly 35 percent efficient.

Table 10: Average Berth Times, Electrical Load, and Total Energy for Ship Visits Using Shore Power

Ship Type	Berth Time (Hours)	Electrical Load (MW)	Total Energy per Visit (MWh)
Container	47	1.2	56.4
Reefer	60	0.6	36
Passenger	15	5.4	81
Tanker	43	0.7	30.1

Source: Starcrest Consulting Group, LLC. 2012. Port of Long Beach Air Emissions Inventory 2011.

Truck Stops

The present number of electrified parking spaces at California truck stops comes from the U.S. Department of Energy's Alternative Fuels Database truck stop electrification locator.[35] There were seven locations with a total of 224 parking spaces in California in 2014. The total number of truck stop parking spaces in California was estimated by SCE to be 9,282. The average usage factor, defined as the fraction of time that trucks utilize the electrified spaces, for the electrified spaces is 0.28, and the average load while connected to an electrified space is 1.39 kW.[36] Truck APUs are generally used to meet anti-idling regulations. The average diesel fuel usage for APUs was estimated to be 0.3 gallons/hour using values from a Nation Academy of Science report (0.2–0.3 diesel gallons/hour) and a North Carolina State University study (0.24-0.41 diesel gallons/hour).[37, 38]

The increase in electrification comes both from increasing the number of electrified spaces and increasing the usage factor. **Table 11** shows the assumptions for both the percentage of electrified spaces and usage factor for these spaces for the low, mid, and high demand cases in 2026.

35 U.S. Department of Energy. *Alternative Fuels Database Truck Stop Electrification Locator.* http://www.afdc.energy.gov/tse_locator.

36 ICF International. 2014. *California Transportation Electrification Assessment Phase 1: Final Report.* http://www.caletc.com/wp-content/uploads/2014/09/CalETC_TEA_Phase_1-FINAL_Updated_092014.pdf.

37 National Academy of Science. Technologies and Approaches to Reducing the Fuel Consumption of Medium- and Heavy-Duty Vehicles. March 2010.

38 Frey, H. Christopher and Kuo, Po-Yao. 2009. *Real-World Energy Use and Emission Rates for Idling Long-Haul Trucks and Selected Idle Reduction Technologies.* Journal of the Air & Waste Management Association 59:7, 857-864, DOI:10.3155/1047-3289.59.7.857.

Table 11: Percentage of Electrified Spaces and Usage Factor for these Spaces in Truck Stops in 2026

Demand Case	Percentage of Electrified Spaces	Usage Factor for Electrified Spaces
Low	2.41	0.5
Mid	20	0.6
High	40	0.6

Source: Aspen team analysis

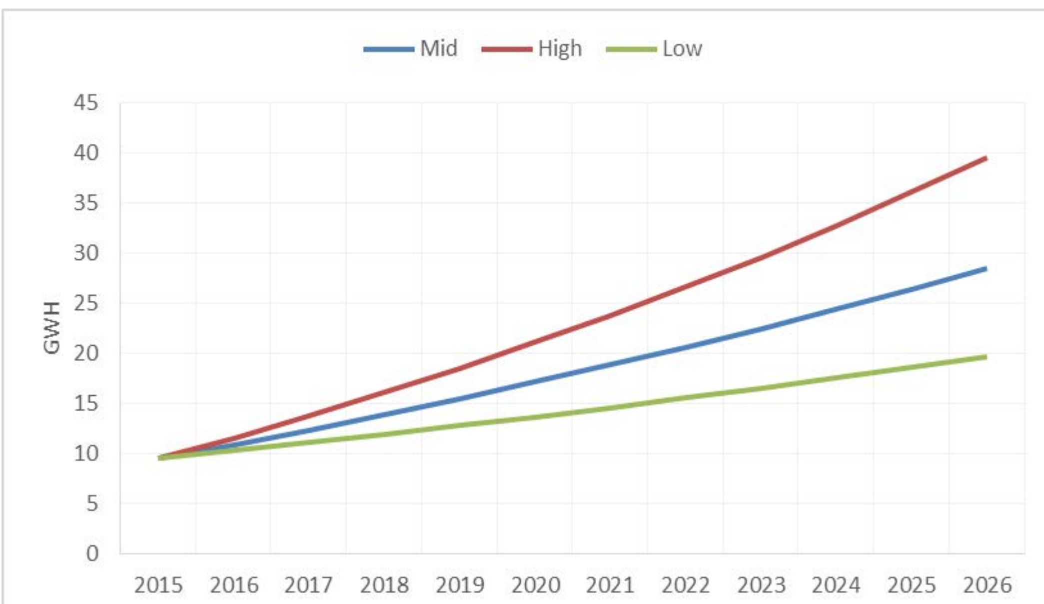
CHAPTER 4:
Off-Road Vehicle Electrification

The California off-road electrification forecast attempts to estimate electricity usage in sectors that are not included elsewhere in the electricity demand models. The sectors include vehicles driving in off-road locations, such as ports or airports, as well as stationary vehicles consuming electricity while operating off-road, such as work trucks at work sites or trucks at truck stops. In most cases, the vast majority of vehicles operate on diesel or gasoline. Due to regulations, the desire to operate cleaner fleets, and economic considerations, vehicle owners have begun to electrify vehicles. When these vehicles operate in electric mode, they either consume electricity or discharge batteries that later must be charged from the electrical grid.

Airport Ground Support Equipment

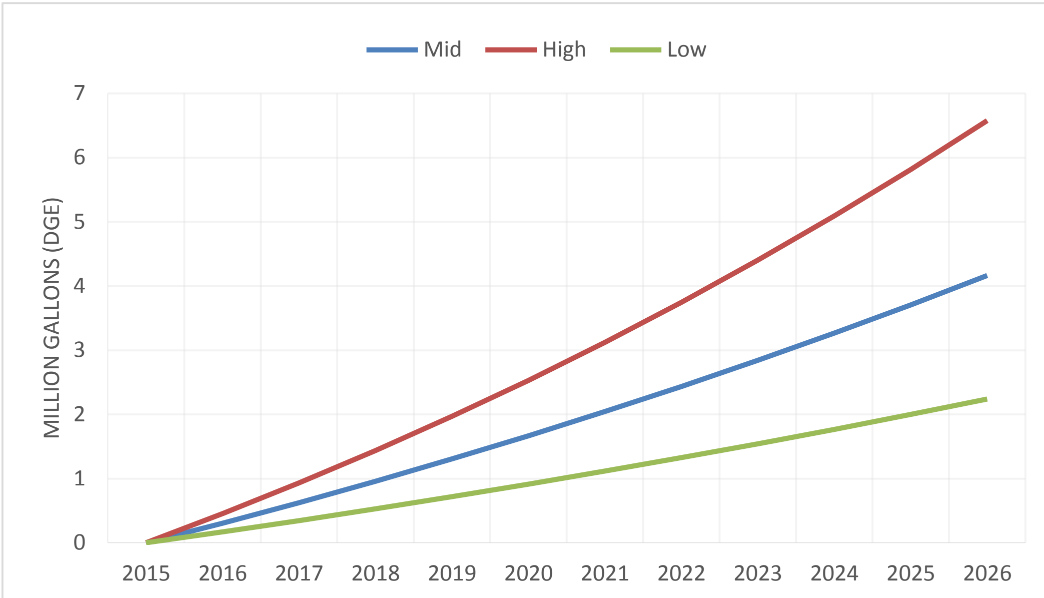
Figures 1 and **2** show the airport GSE forecast for electricity usage and avoided diesel gallon equivalent (DGE) fuel through 2026. The growth rate is a combination of the 2 to 3 percent increase in equipment based on the macroeconomic forecasts and the projected electrification rate (30 to 50 percent). The electrification rate dominates the spread.

Figure 1: Electricity Usage for Airport GSE



Source: Aspen team analysis

Figure 2: Avoided Diesel Gallon Equivalent Usage for Airport GSE

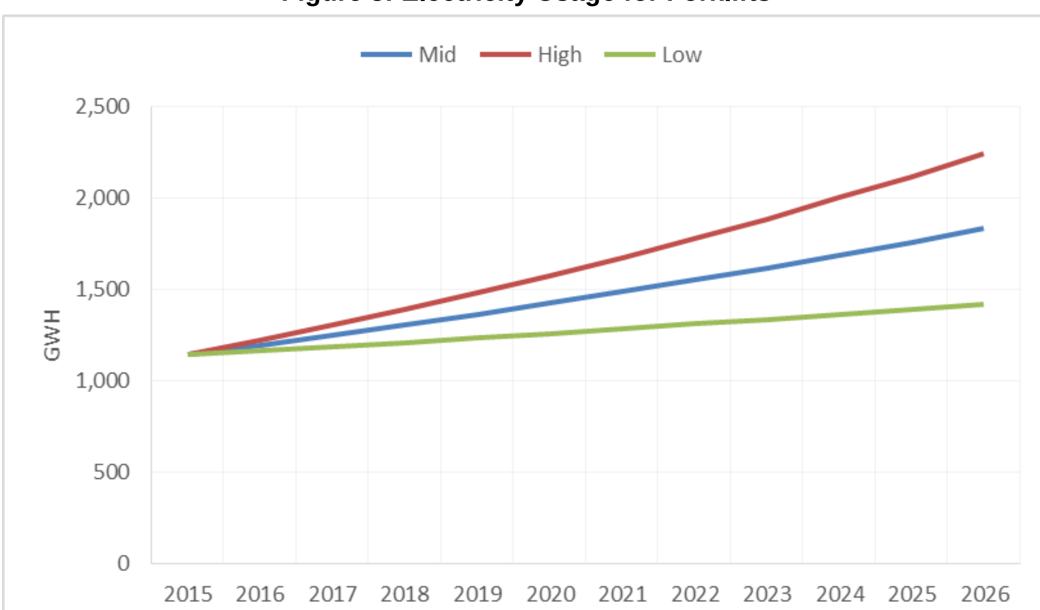


Source: Aspen team analysis

Forklifts

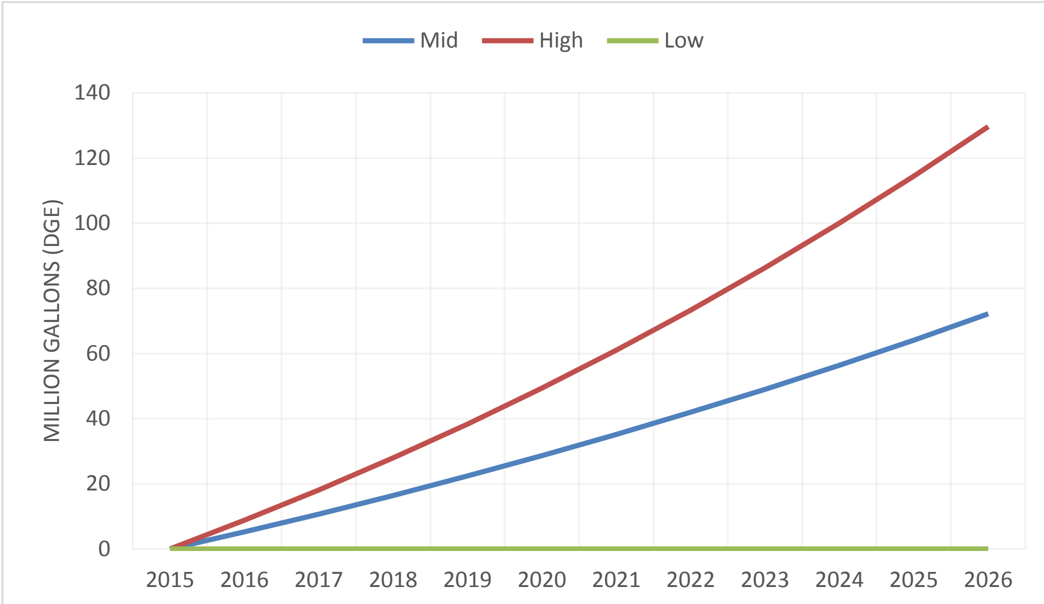
Figures 3 and **4** show the forklift forecast of electricity usage and avoided diesel equivalent fuel through 2026. The growth in forecasted electricity usage is a result of a 2 to 3 percent annual increase in fleet stock and a projected electrification rate of 15 to 25 percent.

Figure 3: Electricity Usage for Forklifts



Source: Aspen team analysis

Figure 4: Avoided Diesel Gallon Equivalent Usage for Forklifts



Source: Aspen team analysis

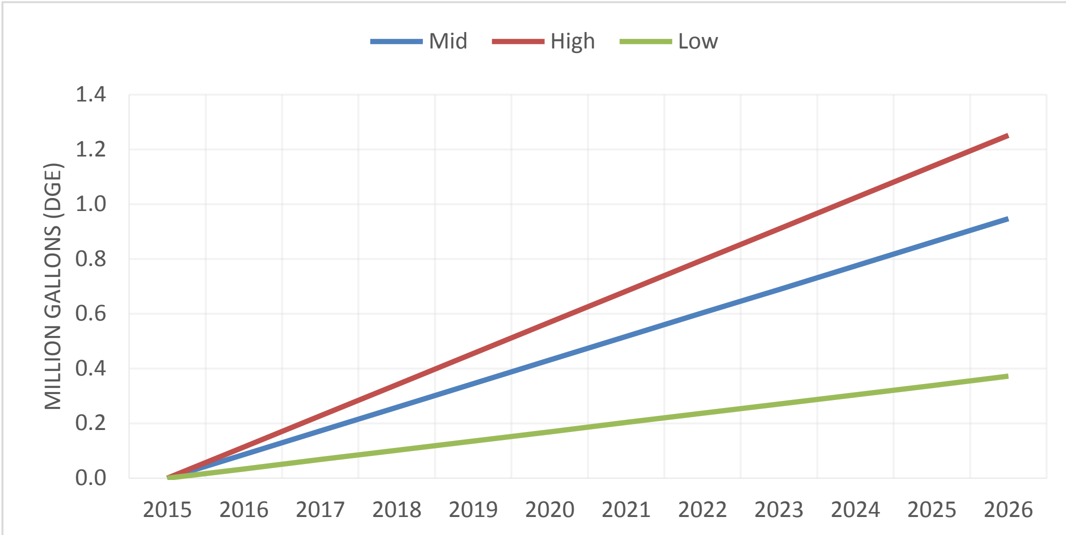
Utility Work Trucks

Figures 5 and **6** show the utility work truck forecast for electricity usage and avoided diesel equivalent fuel through 2026. The increases in electricity usage and avoided DGE usage stem from an annual growth in fleet stock of 2.2 to 3.4 percent and projected increase in electrified stock.

Figure 5: Electricity Usage for Utility Work Trucks

Source: Aspen team analysis

Figure 6: Avoided Diesel Gallon Equivalent Usage for Utility Work Trucks

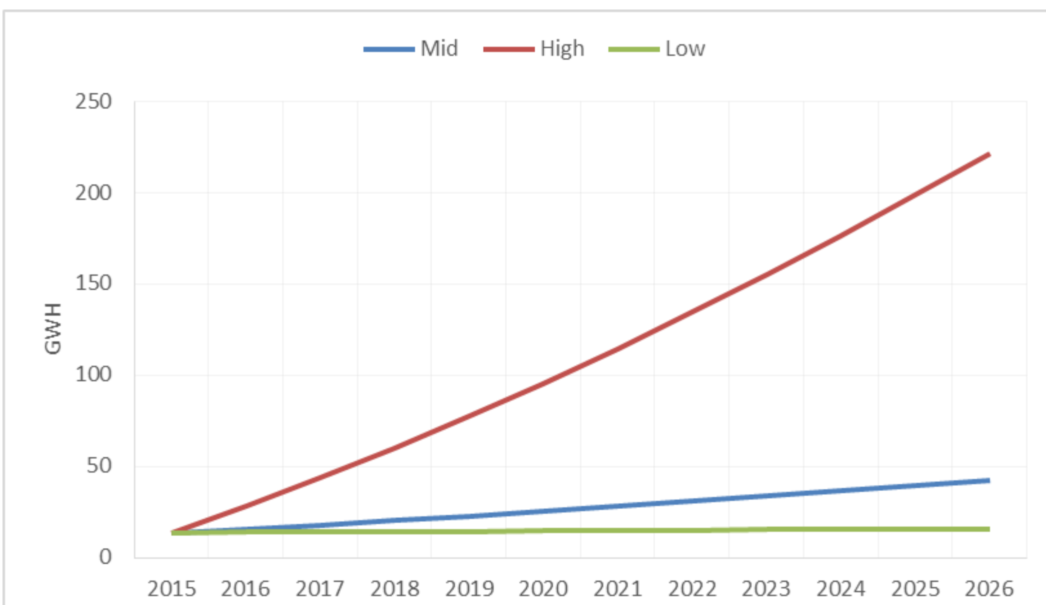


Source: Aspen team analysis

Transportation Refrigeration Units

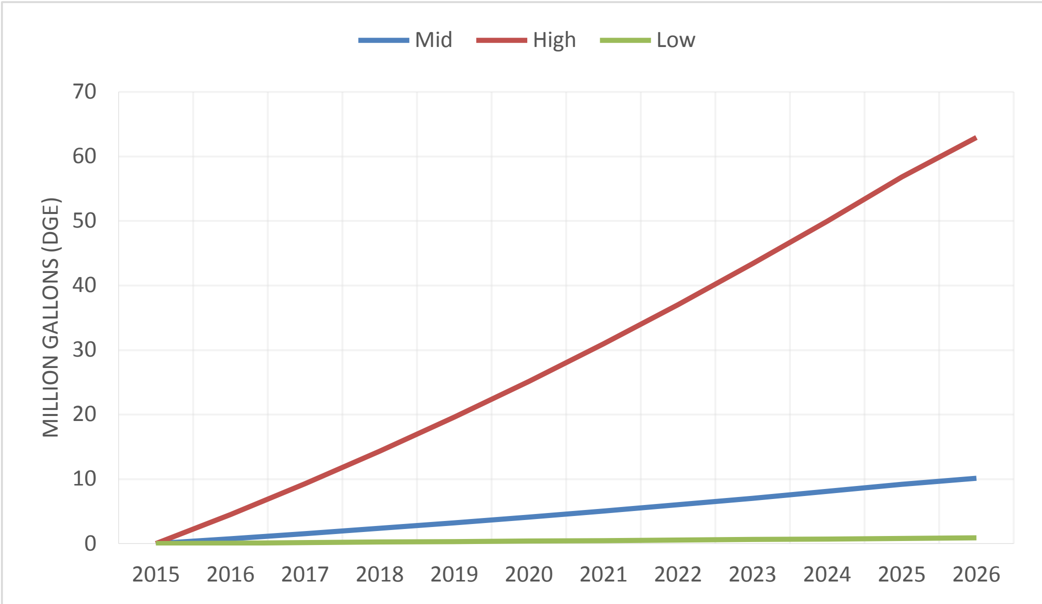
Figures 7 and **8** show the TRU forecast for electricity usage and avoided diesel equivalent fuel through 2026. Electricity usage and DGE usage in the high case are much greater than in the mid and low cases because they assume no electrification for out-of-state TRUs compared to 20 percent electrification in the high case.

Figure 7: Electricity Usage for TRUs



Source: Aspen team analysis

Figure 8: Avoided Diesel Gallon Equivalent Usage for TRUs

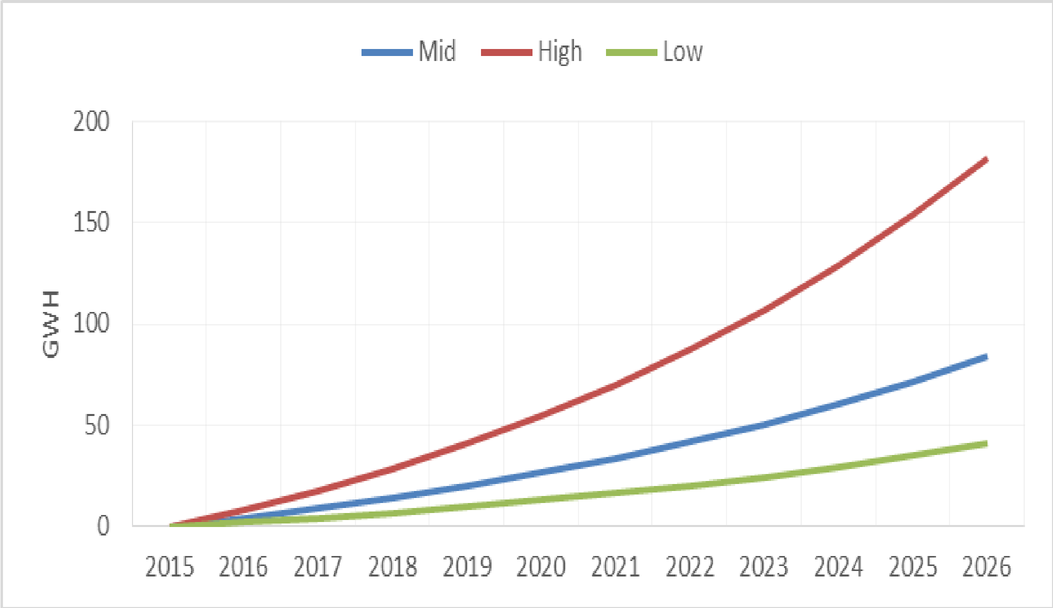


Source: Aspen team analysis

Cargo Handling Equipment

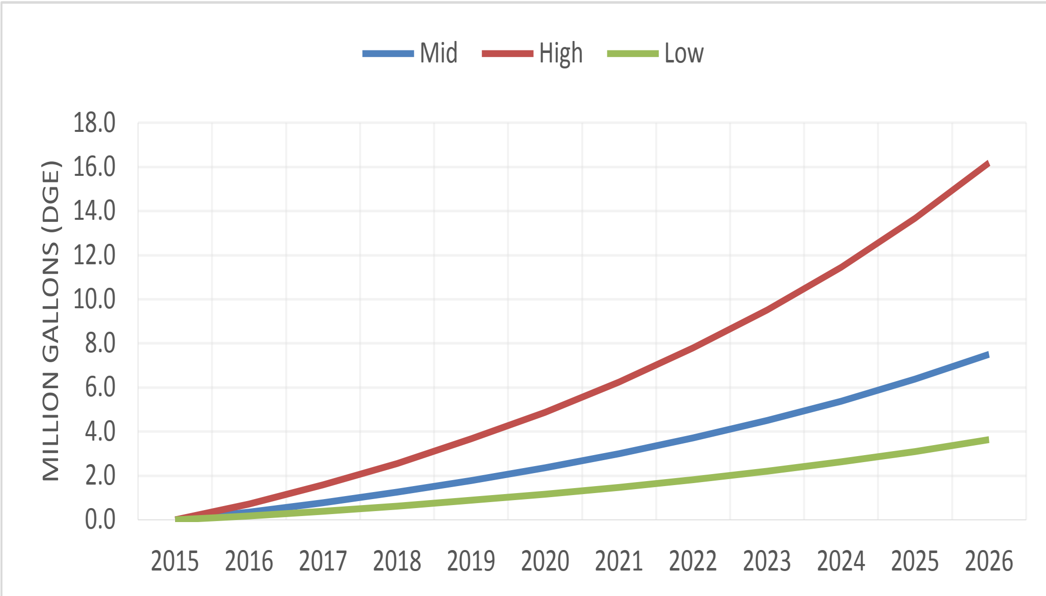
Figures 9 and **10** show the port CHE forecast for electricity usage and avoided diesel equivalent fuel through 2026. The main difference among the low, mid, and high demand cases stems from the percentage electrification assumed for each case. In the low case, electrification reaches only 10 percent (5 percent for RTG cranes) by 2026, while the high case reaches 40 percent (20 percent for RTG cranes) by 2026.

Figure 9: Electricity Usage for Port CHE (Yard Tractors, Forklifts, and RTG Cranes)



Source: Aspen team analysis

Figure 10: Avoided Diesel Gallon Equivalent Usage for Port CHE

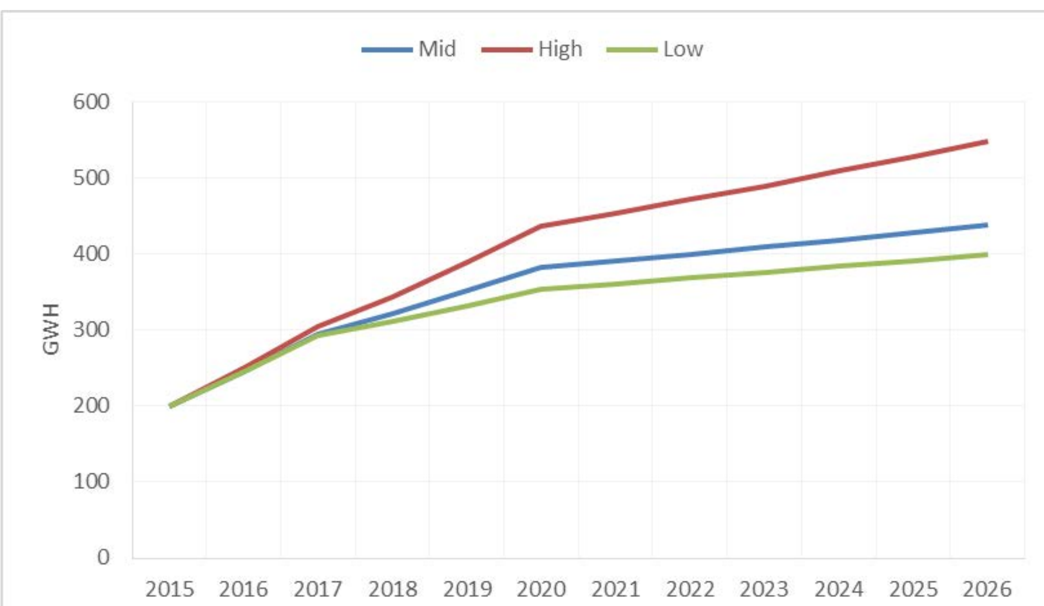


Source: Aspen team analysis

Shore Power

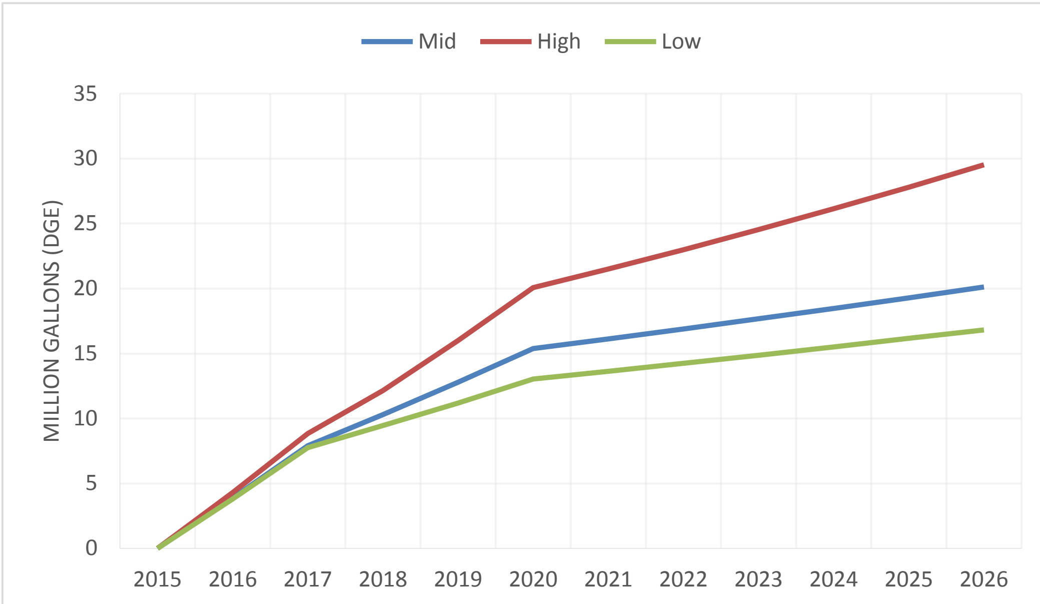
Figures 11 and **12** show the shore power forecast for electricity usage and avoided diesel equivalent fuel through 2026. The 2017 and 2020 kinks in the plots result from changes in the rate of electrification. The At-Berth regulation specifies increased shore power requirements at those years. The electrification increases are linear from 2015-2017, 2017-2020, and after 2020.

Figure 11: Electricity Usage for Shore Power



Source: Aspen team analysis

Figure 12: Avoided Diesel Gallon Equivalent Usage for Shore Power

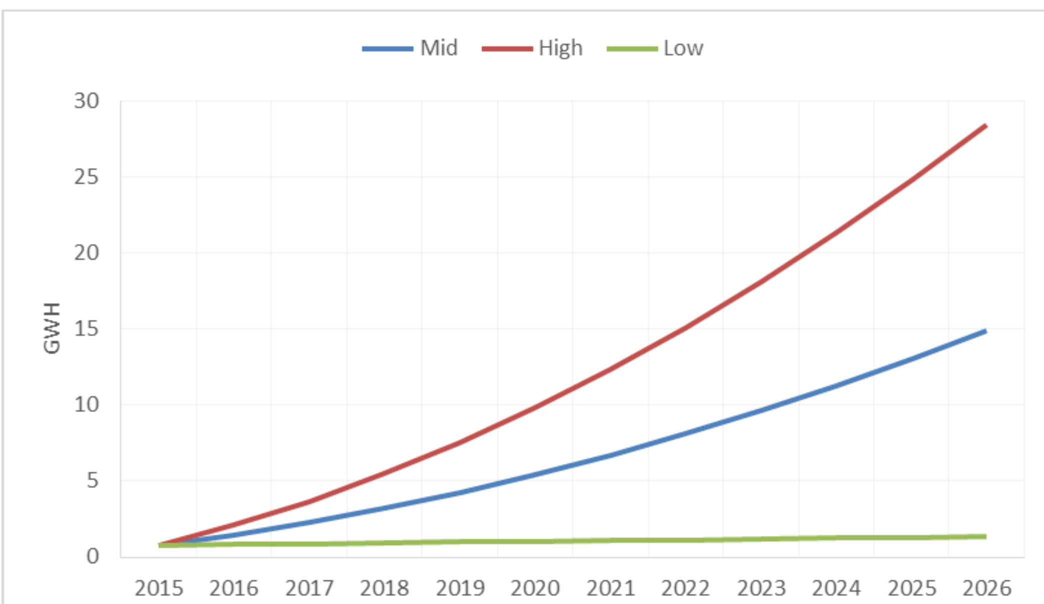


Source: Aspen team analysis

Truck Stop

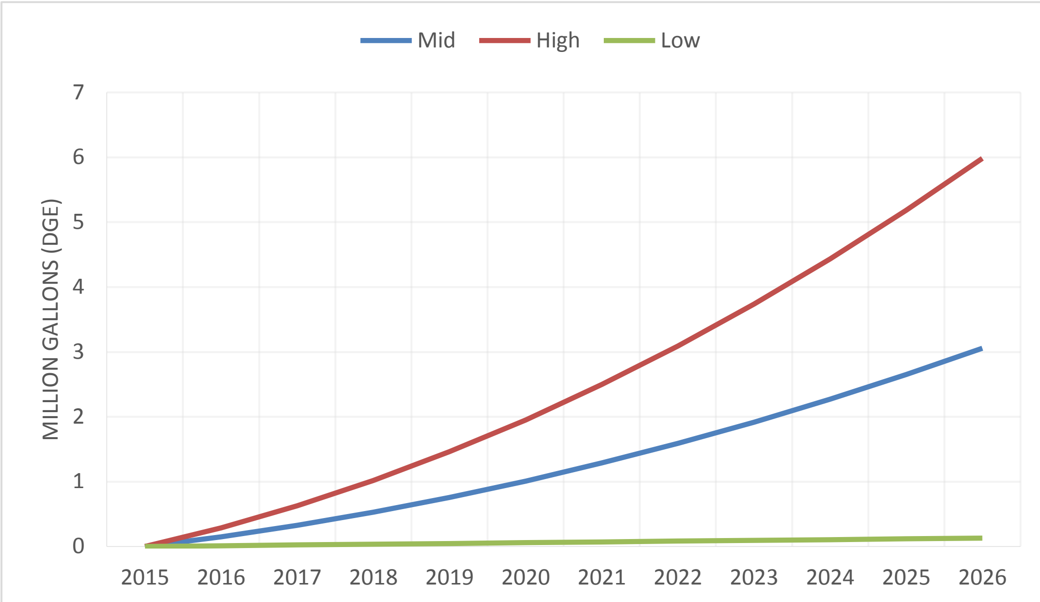
Figures 13 and **14** show the forecast for electricity usage and avoided diesel equivalent fuel through 2026. The low case grows over the period examined but appears to be flat in the graph owing to the scale for illustrating all three cases.

Figure 13: Idled Truck Electricity Usage at Truck Stops



Source: Aspen team analysis

Figure 14: Avoided Fuel Usage by Idled Trucks at Truck Stops, Diesel Gallon Equivalent

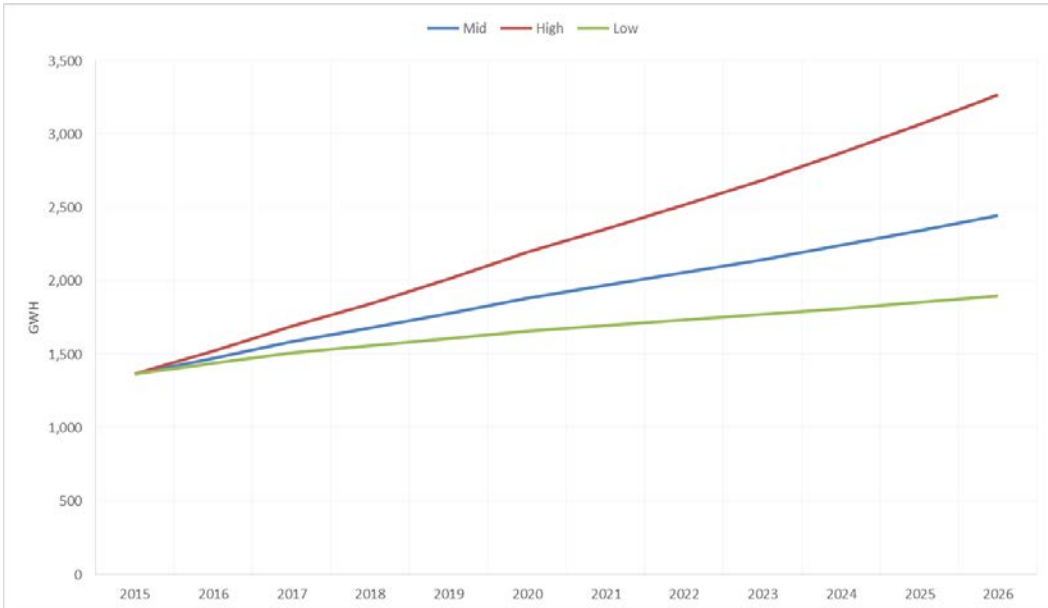


Source: Aspen Team Analysis

Summary of Off-Road Electricity Usage and Avoided Petroleum Consumption

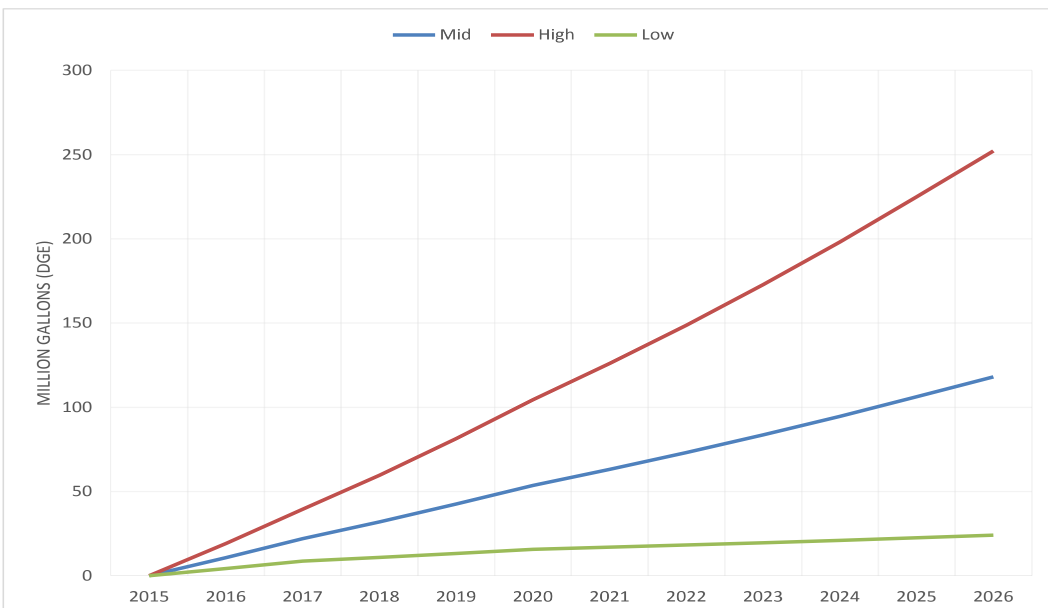
Figures 15 and **16** show the forecast for electricity usage and avoided diesel gallon equivalent fuel through 2026 for off-road vehicles and equipment. The avoided DGE fuel projections represent an increase in avoided DGE relative to 2015. The growth in both electricity usage and avoided petroleum results from a combination of macroeconomic growth and increases in vehicle and equipment electrification. The very slight changes in slope near 2017 and 2020 result from changes in shore power electrification rates due to existing regulations.

Figure 15: Total Electricity Usage for Off-Road Vehicles and Equipment



Source: Aspen team analysis

Figure 16: Avoided Fuel Usage for Off-Road Vehicles and Equipment in Diesel Gallon Equivalent



Source: Aspen team analysis

Table 12 shows the total electricity usage for off-road vehicles and equipment for 2015, 2020, and 2026

Table 12: Total Electricity Usage for Off-Road Vehicles and Equipment

Demand Case	**Electricity Usage (GWh)**		
	2015	**2020**	**2026**
Mid	1,365	1,882	2,445
High	1,365	2,195	3,267
Low	1,365	1,657	1,896

Source: Aspen team analysis

Table 13 shows the increase in avoided petroleum usage for off-road vehicles and equipment for 2020 and 2026 relative to 2015. The avoided petroleum fuel is calculated using the number of equipment or electric vehicles that are assumed to be substituted for petroleum-fueled vehicles or equipment starting in 2016. This results in zero gallons avoided in 2015.

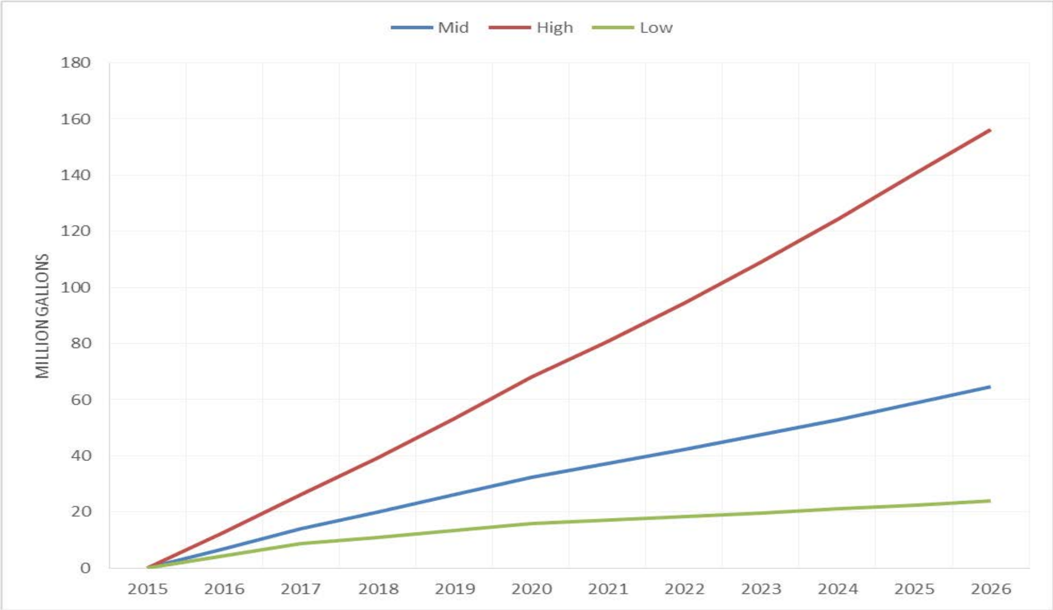
Table 13: Avoided Fuel Usage for Off-Road Vehicles and Equipment, Diesel Gallon Equivalent

Demand Case	Avoided Petroleum Usage (Million Gallons DGE)		
	2015	2020	2026
Mid	0	54	118
High	0	105	252
Low	0	16	24

Source: Aspen team analysis

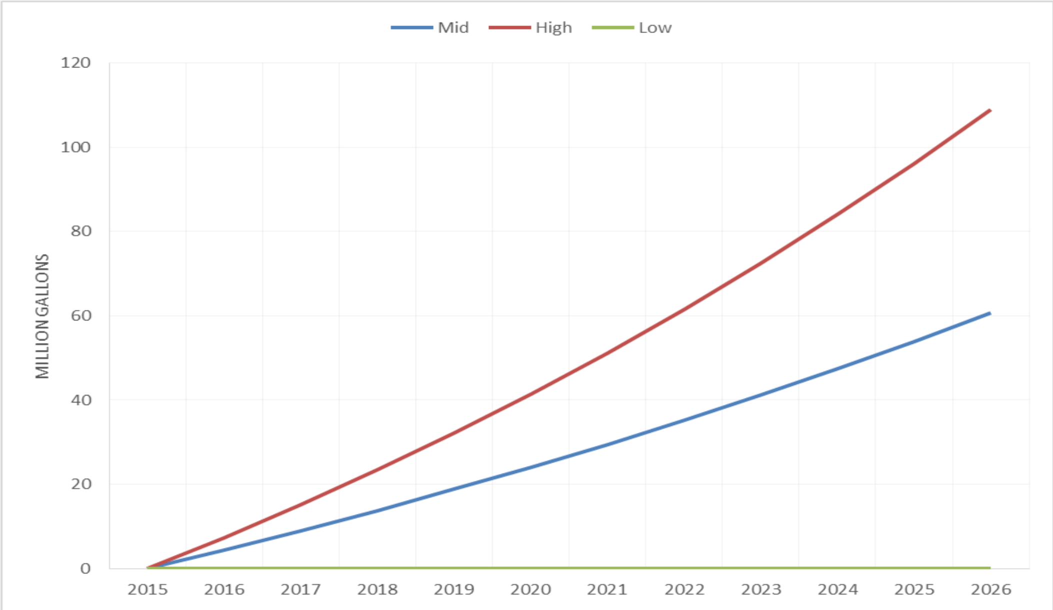
Figures 17 and 18 show the avoided petroleum usage for diesel and gasoline, respectively, relative to 2015. All sectors besides forklifts were assumed to use diesel fuel only. Internal combustion engine forklifts use both diesel and gasoline.

Figure 17: Avoided Diesel Fuel Usage for Off-Road Vehicles and Equipment



Source: Aspen team analysis

Figure 18: Avoided Gasoline Fuel Usage for Off-Road Vehicles and Equipment



Source: Aspen team analysis

Conclusion

This analysis estimates electricity demand for off-road vehicle sectors that were previously not included in the demand forecast. Major results include the following:

- Forklifts dominate the electricity projection, using roughly 75 percent of off-road electricity in the mid demand case by 2026, with shore power second at 18 percent.
- The increase in electricity usage from 2015 to 2026 varies from roughly 500 to 1,900 GWh for the low and high demand case forecasts, respectively.
- This projected increase represents an extremely small change in the overall state electricity demand.

This work can serve as reference for future off-road electricity demand forecasts.

Acronyms and Abbreviations

Acronym/Abbreviation	Original Term
2014 CED	*2014 California Energy Demand*
2015 IEPR	*2015 Integrated Energy Policy Report*
APUs	Auxiliary power units
ARB	California Air Resources Board
CalETC	California Electric Transportation Coalition
CalTEA	*California Transportation Electrification Assessment*
CED	California Energy Demand
CHE	Cargo handling equipment
CHEI	Cargo handling emissions inventory
DGE	Diesel gallon equivalent
Energy Commission	California Energy Commission
eTRU	Electric transport refrigeration units
EV	Electric vehicle
GHG	Greenhouse gas
GSE	Ground support equipment
GSP	Gross state product
IEPR	*Integrated Energy Policy Report*
kWh	Kilowatt hour
LAX	Los Angeles International Airport
MWh	Megawatt hour
PEV	Plug-in electric vehicle
PG&E	Pacific Gas and Electric Company
RTG	Rubber-tired gantry
SCE	Southern California Edison Company
SDG&E	San Diego Gas & Electric Company
SMUD	Sacramento Municipal Utility District

TCU	Transportation, communication, and utilities
TRU	Transport refrigeration units

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APPENDIX A:
Off-road Vehicles and Equipment by Sector

Table A-1: Off-Road Vehicles and Equipment Included in this Study by Sector

Off-Road Sector	Vehicles and Equipment
Airport Ground Support Equipment	A/C tug narrow body A/C tug wide body Baggage tug Belt loader Bobtail Cargo tractor Forklift Lift Passenger stand Other ground support equipment
Industrial Forklifts	Classes 1 and 2 Class 3 Classes 4 and 5
Work Trucks	37' bucket truck 55' bucket truck
TRUs	< 11 hp 11- 25 hp > 25 hp Out of state
Port Cargo Handling Equipment	Forklift RTG crane Yard tractor
Shore Power	Container ships Reefer ships Passenger ships Tanker ships
Truck Stops	Electrified parking spaces

Source: Aspen team analysis